Comparison of Swallowing Characteristics in Patients with Dysphagia and Normal Controls

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Global Contributor to Eco-Techno-Humanopia
AGENDA

- Introduction
  - Background
  - Objective of the Study

- Approach

- Results
  - Swallowing Characteristics: Controls vs. Patients
  - Diagnostic Model for Dysphagia

- Discussion
Dysphagia: Clinical Significance

- **Definition:** difficulty in swallowing food
- **Etiology:** mainly accompanied by neurologic diseases (e.g., stroke) (Daniels et al., 2006)
- **Symptom:** aspiration, pneumonia, dehydration, malnutrition
- **Prevalence:** increased with age, particularly high among older adults (> 60 yrs.) (Morris, 2006; Robbins and Barczi, 2003)

⇒ Because dysphagia improperly diagnosed and/or treated may lead to asphyxiation and death, **early and accurate identification and proper therapy are important**
Swallowing Process

**Oral preparatory phase & Oral phase**
- Moistening
- Mastication
- Trough formation
- Movement of the bolus posteriorly

**Pharyngeal phase**
- Closure of the nasopharynx
- Opening of the auditory tube
- Hyoid elevation
- Bolus transits pharynx
- Peristalsis
- Relaxation

**Esophageal phase**

 ⇒ Oral phase: easy to observe

 ⇒ Pharyngeal phase: difficult to observe → need a *specialized device* to examine swallowing of food inside the pharynx
# Diagnosis Methods for Dysphagia

<table>
<thead>
<tr>
<th>Illustration</th>
<th>VideoFluoroscopic Swallowing Study (VFSS)</th>
<th>Fiberoptic Endoscopic Evaluation of Swallowing (FEES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>Record fluoroscopy images by X-ray and evaluate dysfunctions of swallowing</td>
<td>Insert a flexible endoscope through the nose</td>
</tr>
<tr>
<td>Limitation</td>
<td>▪ Radiation exposure</td>
<td>▪ Invasiveness</td>
</tr>
<tr>
<td></td>
<td>▪ General-purpose device with high price</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Qualitative assessment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Not usable in daily activities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Lack of therapeutic functions for dysphagia</td>
<td></td>
</tr>
</tbody>
</table>

⇒ Need to develop a **device specialized** to dysphagia with **high safety and usability**
Recent Studies for Measurement of Swallowing

- **Swallowing sound measurement by sonar Doppler**

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title</strong></td>
<td>Sonar Doppler as an Instrument of Deglutition Evaluation</td>
<td>Doppler Sonar Analysis of Swallowing Sounds in Normal Pediatric Individuals</td>
</tr>
<tr>
<td><strong>Participants</strong></td>
<td>Brazilian 50 persons (25 females, 25 males; mean age: 32 years, 18 ~ 50 years)</td>
<td>Brazilian 90 persons (45 females, 45 males; 3 groups: 2<del>5, 5</del>10, 10~15 years)</td>
</tr>
<tr>
<td><strong>Apparatus</strong></td>
<td>- H/W: Sonar Doppler</td>
<td>- H/W: Sonar Doppler</td>
</tr>
<tr>
<td></td>
<td>- S/W: VOX METRIA</td>
<td>- S/W: VOX METRIA</td>
</tr>
<tr>
<td><strong>Swallowing food</strong></td>
<td>- Saliva</td>
<td>- Saliva</td>
</tr>
<tr>
<td></td>
<td>- Liquid (10 ml of water)</td>
<td>- Liquid (N.S.)</td>
</tr>
<tr>
<td></td>
<td>- Pasty (10 ml)</td>
<td>- Pasty (N.S.)</td>
</tr>
<tr>
<td><strong>Measures</strong></td>
<td>- Peak intensity</td>
<td>- Peak intensity</td>
</tr>
<tr>
<td></td>
<td>- Peak frequency</td>
<td>- Peak frequency</td>
</tr>
<tr>
<td></td>
<td>- Swallowing duration time</td>
<td>- Swallowing duration time</td>
</tr>
<tr>
<td><strong>Analysis</strong></td>
<td>- Mean ± 95% C.I.</td>
<td>- Mean ± 95% C.I.</td>
</tr>
<tr>
<td></td>
<td>- Gender, age, swallowing food effects (ANOVA)</td>
<td>- Gender, age, swallowing food effects (ANOVA)</td>
</tr>
</tbody>
</table>

⇒ **Limitation**: Sounds measured include those not related to swallowing (e.g., respiration, voice production)
Comparison of Swallowing Characteristics in Patients with Dysphagia and Normal Controls Using a Ultrasonic Doppler Sensor

1. Development of a swallowing measurement and analysis system
2. Quantification of the swallowing function in the pharyngeal phase
3. Comparison of dysphagic patients with normal controls
4. Establishment of a diagnostic model for dysphagia
Research Protocol

S1. System development
- Ultrasonic Doppler sensor
- Swallowing measurement S/W

S2. Quantification
- Swallowing measures
- Quantification S/W

S3. Experiment
- Dysphagic patients vs. normal controls
- Various swallowing types and volumes

S4. Analysis
- Pairwise comparison
- Diagnostic model
Measurement: movement of organs related to the pharynx

Ultrasonic Doppler Sensor

Sensor specification (Model: DEPST-D2M5C)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2 MHz</td>
</tr>
<tr>
<td>Element count</td>
<td>5</td>
</tr>
<tr>
<td>Element length</td>
<td>5 mm</td>
</tr>
<tr>
<td>Kurf</td>
<td>1 mm</td>
</tr>
<tr>
<td>Pitch</td>
<td>6 mm</td>
</tr>
<tr>
<td>Element width</td>
<td>6 mm</td>
</tr>
<tr>
<td>Wire</td>
<td>Micro coaxial cable (100pF)</td>
</tr>
<tr>
<td>Transducer surface radius</td>
<td>158R</td>
</tr>
</tbody>
</table>
Case for housing the sensor; flexible band for locating the sensor to the neck securely.
S1. Development: **Analysis S/W**

- Real-time plotting of swallowing signal measurements
- Interoperating with VFSS images

![Graph showing real-time plotting and VFSS images](image-url)
S2. Quantification: Signal Processing

S1. Signal *rectification*: (-) values → (+) values

S2. **Smoothing** by the moving average method

- Lag $n = 50$

S3. Starting and ending points **detection**

- Detecting slope = 0.9

S4. Peak **detection**

- Cutoff = 50
S2. Quantification: Measures

- Peak amplitude
- No. of peaks
- Duration
- Peak-to-peak interval
- Impulse

- 1st peak
- 2nd peak

- Amplitude (mV)
- Time (ms)
Automatic extraction of five swallowing quantification measures

Input:
- Lag $n$
- Slope
- Cut off

Output:
swallowing quantification measures

Interactive adjustment function
S3. Experiment: Method

- Participants: 120 normal controls (NC), 36 dysphagic patients (DP)

- Swallowing types and volumes (# repetitions = 3)
  - Dry saliva (DS)
  - Thin liquid (TN; water): 1, 3, 9 ml
  - Thick liquid (TK; beverage with thickener): 1, 3, 9 ml

<table>
<thead>
<tr>
<th></th>
<th>20s</th>
<th>30s</th>
<th>40s</th>
<th>50s</th>
<th>60s</th>
<th>70s</th>
<th>80s</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>-</td>
<td>60</td>
</tr>
<tr>
<td>Male</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>-</td>
<td>60</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>-</td>
<td>120</td>
</tr>
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</table>

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<tr>
<th></th>
<th>20s</th>
<th>30s</th>
<th>40s</th>
<th>50s</th>
<th>60s</th>
<th>70s</th>
<th>80s</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Male</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>6</td>
<td>12</td>
<td>5</td>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>13</td>
<td>9</td>
<td>5</td>
<td>36</td>
</tr>
</tbody>
</table>

⇒ Age distribution of DPs over age 50 = 94%
⇒ Gender ratio of DPs → female: male = 2: 5
⇒ Swallowing volumes of DPs in the study: up to 3 ml (difficult to swallow 9 ml)
S3. Experiment: Apparatus

- Web cam
- Lemon image
- Analysis S/W
- Gel
- Water
- Beverage
- Thickener
- Swallowing measurement device
- Measuring cup
- Tapeline
- Band & Case
- Measuring spoon (1.25, 2.5, 5 ml)
- Anthropometer
- (1.25, 2.5, 5 ml)
S3. Experiment: Protocol

S1. Informed consent

S2. Practice

S3. Main experiment

S4. Debriefing

Experiment time: 20 min

Finding a location on the neck for good signal acquisition

※ Swallowing order: randomized
※ Rest time bwn. swallowing: 5 sec

< Example >

Session 1: thin liquid 3, 1, 9 ml

30 sec

Session 2: saliva

30 sec

Session 3: thick liquid 9, 3, 1 ml

5 min

17 / 25
S3. Experiment: Demonstration
S4. Result: Swallowing Peak Types

**Normal controls**
- Short-double peak signal (43%)
- Short-single peak signal (39%)
- Short-multiple peak signal (18%)

**Dysphagic patients**
- Short-double peak signal (58%)
- Long-double peak signal (33%)
- Long-multiple peak signal (9%)
S4. Result: NC vs. DP

<table>
<thead>
<tr>
<th>Measure</th>
<th>NC</th>
<th>DP</th>
<th>Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>1</td>
<td>&gt; 0.63</td>
<td>⇓</td>
</tr>
<tr>
<td>Duration</td>
<td>1</td>
<td>&lt; 2 ~ 4</td>
<td>⇑</td>
</tr>
<tr>
<td># peaks</td>
<td>1</td>
<td>&lt; 2</td>
<td>⇑</td>
</tr>
<tr>
<td>P-P interval</td>
<td>1</td>
<td>&lt; 2</td>
<td>⇑</td>
</tr>
<tr>
<td>Impulse</td>
<td>1</td>
<td>&gt; 0.67</td>
<td>⇓</td>
</tr>
</tbody>
</table>

* * * p < 0.05

**Amplitude**
- NC: 1st peak
- NC: 2nd peak
- DP: 1st peak
- DP: 2nd peak

**Duration**

**# peaks**

**P-P interval**

**Impulse**

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*Ergonomic Design Technology Lab*
S4. Diagnostic Model: Method

### Covariates

- **Amplitude (mV)**
  - Highest peak
  - 2nd highest peak
  - Highest - 2nd highest peak
  - Average peak

- **Duration (msec)**

- **# peaks (unit)**

- **Interval (msec)**
  - Longest peak interval
  - 2nd longest peak interval
  - Highest - 2nd highest interval
  - Average peak interval

- **Impulse (mV x msec)**

### Factors

- **Age (year)**

- **Gender (female, male)**

### Cumulative logit model (ordinal logistic regression)

### Degree of dysphagia

- 0: normal
- 1: mild
- 2: moderate / severe

⇒ Used data: TN 1 ml for practicality

⇒ Eliminated data of 5% by ±2SD and CV < 0.5
## S4. Diagnostic Model: Performance

<table>
<thead>
<tr>
<th>Predicted class</th>
<th>Actual class</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Mild</td>
<td>Moderate &amp; Severe</td>
</tr>
<tr>
<td>Normal</td>
<td>120</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Mild</td>
<td>0</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Moderate &amp; Severe</td>
<td>0</td>
<td>4</td>
<td>13</td>
</tr>
</tbody>
</table>

※ $n = 151$

- Specificity = 100%
- Sensitivity for mild = 76%
- Sensitivity for moderate/severe = 93%
Discussion

- Quantitative swallowing assessment of the movement of the phalangeal organs using an ultrasonic Doppler sensor

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<td>P-P Interval</td>
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<tr>
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<td>1</td>
<td>&gt; 0.67</td>
</tr>
</tbody>
</table>

⇒ Dysphagic patients: more swallowing due to impaired movement in the pharynx by stenosis or dysfunction → amplitude ↓, duration ↑

- Diagnostic model development for the severity of dysphagia: normal, mild, moderate/severe (specificity = 100%, sensitivity for mild = 76%, sensitivity for M/S = 93%)

⇒ Clinically effective system for dysphagia diagnosis using measurements from swallowing only 1 ml of water
Future Study

- Interoperation with dysphagia therapy technology

⇒ Assist swallowing in real-time by interoperating with a functional electrical stimulation (FES) system (automatic stimulation of neck muscle at the right time)
Thank You for your attention!